

# COMPARISON OF UPPER LIMB JOINT FORCES DURING STRAIGHT LINE AND TURNING WHEELCHAIR MANEUVERS

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**Abstract**—The objective of this study was to explore the joint kinetics of upper extremities during wheelchair maneuvers. A high incidence of musculoskeletal injuries has been reported due to the overuse and high repetitive motion of wrist, elbow and shoulder during wheelchair propulsion. Studies have been conducted with the use of a dynamometer or treadmill to simulate propulsion on level or inclined surface. However, during indoor maneuvering, turning is unavoidable. Three unimpaired subjects were recruited to perform three types of wheelchair maneuvers: straight line propulsion, turning left and turning right for ninety degrees with their comfortable speed. Using the SMART<sup>Wheel</sup>s and the motion analysis system (Vicon 370, Oxford), joint loadings were determined. The results showed that during turning, the side that held the wheel steady had greater peak joint reaction forces than that of the side which pushed the wheel forward. The results also indicated that the peak joint reaction forces during turning are larger than forces encountered during straight-line propulsion. In straight line propulsion, larger joint forces were found on the dominant side. However, larger joint loadings were found on the non-dominant arm holding the wheel during turning than the dominant side when the dominant hand was holding the wheel during turning. Similar results were also observed for the arms pushing the wheel forward during turning i.e. the non-dominant arm tended to exert larger efforts compared to the dominant arm.

**Keywords** – Joint forces, upper limbs, wheelchair

## I. INTRODUCTION

In the United States, there were 1,564,000 wheelchair users based on a report in 1994 [1]. During manual wheelchair propulsion, upper extremities are the major source of power. Owing to the overuse and high repetitive motion of the wrist, elbow and shoulder, high incidents of musculoskeletal injuries have been reported [2-5].

Many studies in the past have focused on level or inclined surfaces using dynamometer or treadmill [6-7]. In daily life, wheelchair propulsion includes not only straight-line movement, but also turning motion. Especially in indoor environment, turning motion is frequently performed. This repetitive movement could generate unwanted stresses at the wrist, elbow and shoulder joints probably resulting in further secondary disability. The objective of this study was to explore the joint kinetics of the upper extremities during various types of wheelchair maneuvers.

## II. METHODS

### A. Subject selection

Three unimpaired subjects who had no complaint of pain in their upper extremities in the last 6 months were recruited. All of them are right hand dominant. They were all able to understand the instructions and to provide informed consent.

### B. Kinetic system

SMART<sup>Wheel</sup>s were used to collect kinetic data. These wheels are modified mag wheels, instrumented with a three-beam system which allows for the determination of three-dimensional forces and moments occurring at the pushrim [8-10]. It has a precision of 2 Newton and a resolution of 0.2 Newton at a data collection rate of 240 Hz [8].

### C. Kinematic system

Kinematic information was measured using a six-camera motion analysis system (Vicon 370, Oxford). This system is capable of collecting real-time and three-dimensional data. In this study, fifteen reflective markers were attached to the subject's skin overlying the T5, acromion process, lateral side of the mid-upper arm, medial epicondyle, lateral epicondyle, radial styloid, ulnar styloid and the second metacarpophalangeal joint of the subjects [11]. Another three markers were placed each side on the rear wheel axle and the beams of the SMART<sup>Wheel</sup>s to track the orientation of the wheels. Fig 1 showed the local coordinate systems of the joints of the left upper extremity. All kinematic data were collected at 60Hz.

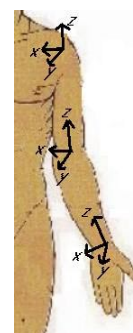


Fig. 1 Local coordinate system of the wrist, elbow and shoulder of the left upper extremity.

### D. Data Collection

The anthropometric data of each subject were recorded for the calculation of joint kinetics. Three kinds of

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wheelchair maneuvers were included in this study: (1) turning left for ninety degrees (2) turning right for ninety degrees, and (3) straight line propulsion. In turning, the subjects were instructed to hold one of the wheels steady while the other was pushed forward.

For each type of maneuvers, a prescribed pathway was labeled on the ground for guidance and three testing trials were taken. Subjects were asked to propel along the prescribed pathways at their comfortable speed and they were allowed to perform a few trials to get familiar with the experimental set-up. In order to minimize the possible training effect, the sequence of maneuvers was randomized. In each trial, kinetic and kinematic data were collected for 20 seconds in synchrony and subjects had one-minute rest between trials.

### III. RESULT

Peak joint reaction forces of the wrist, elbow, and shoulder joint of both upper extremities were analyzed in three directions with reference to the local coordinate system: (1)  $F_x$  (medial-lateral) (2)  $F_y$  (anterio-posterior) (3)  $F_z$  (longitudinal) as shown in Fig. 1. All the joint force directions are with respect to the segment distal to the joint. The results for each type of maneuvers were the averages of three testing trials.

#### A. Peak joint reaction forces during straight-line propulsion

In straight line propulsion, the peak joint reaction forces at the wrist, elbow and shoulder of the dominant arm of three subjects were greater than that of the non-dominant one.

The maximum peak medial directed  $F_x$  and downward  $F_z$  were found at the wrist joint on both sides of the upper extremities (see Fig. 2) and the maximum peak anterior directed  $F_y$  was found at the shoulder joint (see Table 1). Among the wrist, elbow and shoulder joint of the arms, all peak joint reaction forces were pointed medially, anteriorly, and downward.

#### B. Peak joint reaction forces during turning

In right turning, the left arm (non-dominant side) was used to push the wheel forward while it was the right arm (dominant side) when turning left. Except from the peak  $F_x$ , both peak  $F_y$  and  $F_z$  were found to be higher on the non-dominant side (see Fig. 3, Table 2). In addition, the pattern of movement and force application of the upper extremities was in general similar to that of straight-line propulsion.

With respect to the peak joint reaction forces during straight-line propulsion, on the non-dominant side, the peak  $F_x$ ,  $F_y$  and  $F_z$  during turning were higher than that of the non-dominant arm during straight-line propulsion.

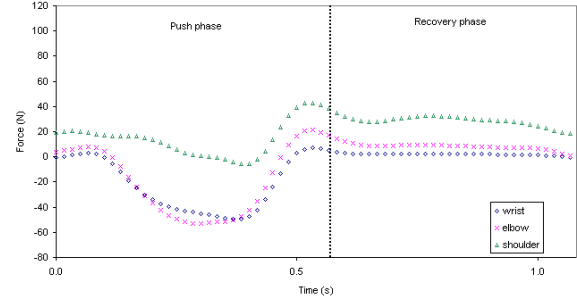


Fig. 2  $F_z$  at three joints of the right upper extremity of subject A during straight line propulsion

TABLE 1  
PEAK JOINT REACTION FORCES OF UPPER EXTREMITIES  
DURING STRAIGHT LINE PROPULSION (SUBJECT A)

	Dominant arm (mean $\pm$ S.D.)		
Peak joint reaction force (Newton)	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	15.4 $\pm 6.48$	11.09 $\pm 5.03$	-0.33 $\pm 8.61$
Peak $F_y$ (anterior as positive)	38.49 $\pm 1.78$	25.15 $\pm 3.61$	45.38 $\pm 4.46$
Peak $F_z$ (upward as positive)	-61.47 $\pm 5.46$	-59.34 $\pm 4.35$	-12.64 $\pm 13.45$
	Non-dominant arm (mean $\pm$ S.D.)		
Peak joint reaction force (Newton)	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	11.62 $\pm 8.17$	6.22 $\pm 7.98$	-2.73 $\pm 5.58$
Peak $F_y$ (anterior as positive)	28.04 $\pm 6.76$	17.41 $\pm 3.8$	31.73 $\pm 8.16$
Peak $F_z$ (upward as positive)	-41.74 $\pm 7.86$	-41.09 $\pm 10.11$	-6.04 $\pm 11.66$

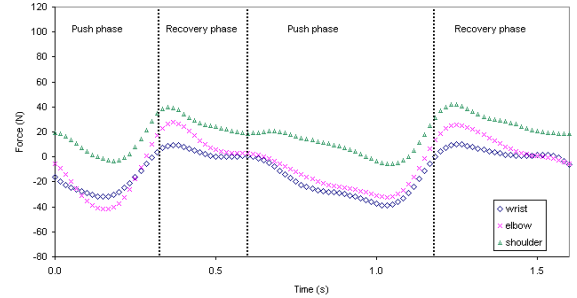


Fig. 3  $F_z$  at three joints of the dominant arm of subject B during left turning

TABLE 2  
PEAK JOINT REACTION FORCES ON THE SIDE THAT PUSHED  
THE WHEEL FORWARD DURING TURNING (SUBJECT A)

	Left turning (dominant arm, mean $\pm$ S.D.)		
Peak joint reaction force (Newton)	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	14.52 $\pm 5.35$	10.77 $\pm 0.75$	-4.01 $\pm 8.73$
Peak $F_y$ (anterior as positive)	32.6 $\pm 6.75$	22.99 $\pm 3.47$	40.15 $\pm 17.94$
Peak $F_z$ (vertical upward as positive)	-57.94 $\pm 11.98$	-52.58 $\pm 19.23$	-14.53 $\pm 3.77$
	Right turning (non-dominant arm, mean $\pm$ S.D.)		
Peak joint reaction force (Newton)	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	13.23 $\pm 6.73$	4.76 $\pm 2.54$	-0.057 $\pm 0.2$
Peak $F_y$ (anterior as positive)	30.86 $\pm 6.83$	12.67 $\pm 0.079$	59.39 $\pm 13.76$
Peak $F_z$ (vertical upward as positive)	-68.49 $\pm 10.1$	-70.49 $\pm 13.58$	-10.87 $\pm 2.2$

On the side that was holding the wheel during turning, all peak joint loadings, except  $F_y$ , were found to be higher on the non-dominant side. The direction of the joint reaction forces was opposite to that during straight-line propulsion (see Fig. 4), they were directed laterally, posteriorly and upward (see Table 3). The maximum peak  $F_x$  was found at the elbow joint of both arms and the maximum posteriorly directed  $F_y$  was found at the shoulder joint.

Generally, the magnitude of the peak joint reaction forces on the side that held the wheel steady during turning was greater than that of straight-line propulsion and that of the side which pushed the wheel forward during turning.

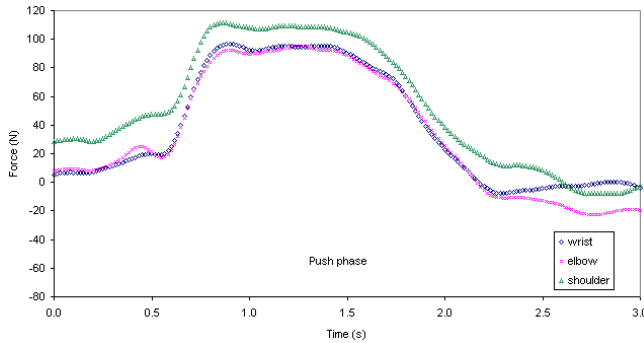


Fig. 4  $F_z$  at three joints of the non-dominant arm of subject C during left turning

TABLE 3  
PEAK JOINT REACTION FORCES ON THE SIDE THAT HELD THE  
WHEEL STEADY DURING TURNING (SUBJECT A)

Peak joint reaction force (Newton)	Left turning (non-dominant arm, mean $\pm$ S.D.)		
	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	-44.45 $\pm 0.11$	-94.94 $\pm 0.19$	-21.21 $\pm 0.7$
Peak $F_y$ (anterior as positive)	15.38 $\pm 10.88$	-13.58 $\pm 0.086$	-62.19 $\pm 0.35$
Peak $F_z$ (vertical upward as positive)	95.62 $\pm 1.06$	92.97 $\pm 1.74$	111.37 $\pm 0.16$
Peak joint reaction force (Newton)	Right turning (dominant arm, mean $\pm$ S.D.)		
	Wrist	Elbow	Shoulder
Peak $F_x$ (medial as positive)	13.93 $\pm 1.26$	-23.11 $\pm 8.65$	11.46 $\pm 3.08$
Peak $F_y$ (anterior as positive)	-26.21 $\pm 3.23$	-31.46 $\pm 0.62$	-81.56 $\pm 2.65$
Peak $F_z$ (vertical upward as positive)	86.12 $\pm 4.67$	90.56 $\pm 3.5$	82.27 $\pm 7.89$

#### IV. DISCUSSION

The results obtained from this pilot study suggested that the peak joint reaction forces during turning are larger during turning as compared to straight-line propulsion. Besides, differences were also found between the joint loadings of the dominant and non-dominant arm in wheelchair maneuvers.

Greater peak joint loadings were found at the joints of the right upper extremity in straight-line propulsion, this may due to the hand dominance of the subjects. However, during turning, the side with higher peak joint reaction forces is on the non-dominant arm. This may be due to the fact that during turning, subjects would use extra care with their non-dominant arm. This would cause them to exert large forces to the pushrim to achieve a successful turning motion. The kinetic results revealed that instead of holding the wheel steadily as instructed, all subjects tried to apply force to propel the wheel in the opposite direction during turning.

The large joint reaction forces on the side that held the wheel during turning could be affected by the speed of turning, flooring material, smoothness of propulsion before turning, propulsion style and also the wheeling experience of the subjects.

These larger joint reaction forces may have a role in the injury mechanisms among wheelchair users. Further studies should be conducted with larger sample sizes and also include experienced wheelchair users to determine if there are any difference between the results of unimpaired subjects and experienced wheelchair users during wheelchair maneuvers, especially during turning motion.

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